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Abstract. The first measurements of hydrodynamic instability growth at the fuel-ablator interface in an ICF implosion are reported. Previous instability measurements on the National Ignition Facility have used plastic capsules to measure ablation front Rayleigh-Taylor growth with the Hydro.-Growth Radiography (HGR) platform. These capsules substituted an additional thickness of plastic ablator material in place of the cryogenic layer of Deuterium-Tritium (DT) fuel. The present experiments are the first to include a DT ice layer, which enables measurements of the instability growth occurring at the fuel-ablator interface. This growth occurs in two ways through separate experiments. In the first case, a perturbation on the outside of the capsule feeds through and grows on the interface. Comparisons to an implosion without a fuel layer produce a measure of the fuel's modulation. In the second case, a modulation was directly machined on the inner ablator before the fuel layer was added. The measurement of growth in these two scenarios are compared to 2D rad-hydro modeling.

1. Introduction

Understanding and mitigating the hydrodynamic instability growth that occurs during the implosion of an inertial confinement fusion (ICF) capsule is important for improving performance in experiments on the National Ignition Facility (NIF). This has been the focus of an experimental campaign using face-on radiography to measure the in-flight growth of pre-imposed perturbations[1, 2]. Thus far, good agreement between simulations and the observed growth has been found at several mode numbers and using several pulse shapes. These hydro-growth radiography (HGR) measurements were made on gas-filled plastic capsules (called symmetry capsules or "symcaps"), where the thickness of the ablator is increased to compensate for the missing DT fuel mass. Recently the first experiments directly measuring instability growth in the presence of a DT ice layer have been conducted and are reported here.

2. Experimental Setup

These experiments introduce perturbations at the interface between the DT fuel and the CH ablator in two different ways. The first uses the same outer-surface perturbation as in a companion symcap experiment. In the layered implosion, these perturbations feed through to

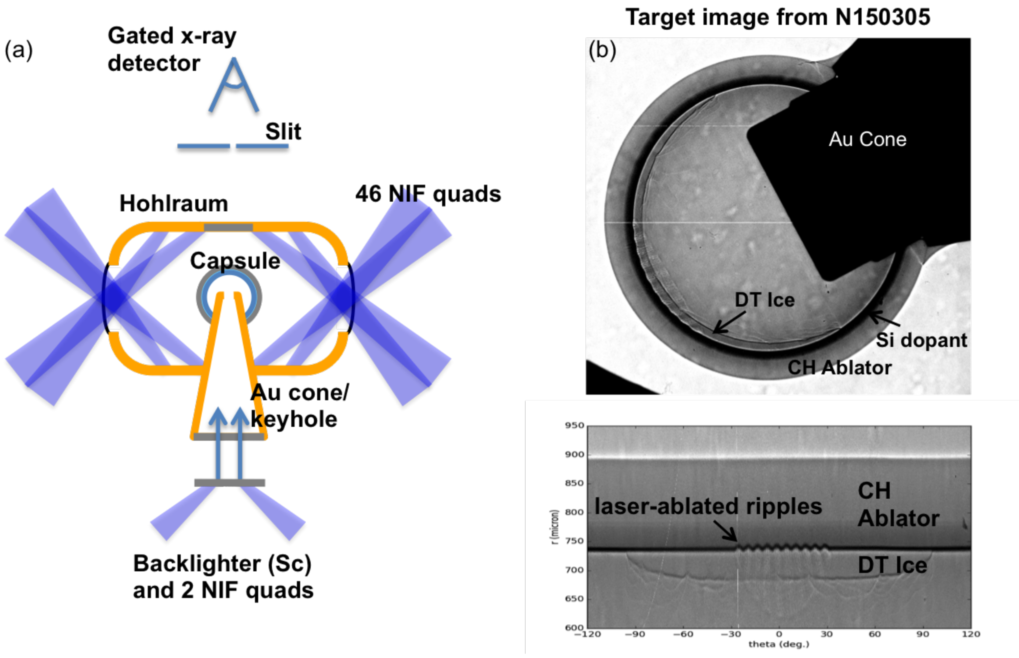

Figure 1. (a) Experimental setup of the hydro.-growth radiography platform. (b) Target image viewed through the laser entrance hole during cryogenic layering. The capsule, the cone, and the ice layer can be seen. Below shows the same image unrolled into radius vs. angle.

the interface and grow through the Rayleigh-Taylor and Richtmyer-Meshkov instabilities. The effect on the interface is identified by comparison with the symcap experiment. In the second experiment, a perturbation is machined directly on the inner ablator surface, between the DT ice and the CH plastic.

The setup for these experiments is shown in Fig. 1(a). The capsule is placed on an Au cone, centering it within the Au hohlraum. Of NIF's 192 laser beams, 184 are directed into the hohlraum, with the remaining 8 laser beams pointed towards a scandium backlighter, creating 4.5 keV x-rays. The backlighter x-rays pass down the axis of the cone, through half the shell of the capsule as it is imploding, out a high-density carbon (HDC) window in the wall of the hohlraum, through a 12 μm wide slit, and finally are recorded by the gated x-ray detector (GXD). The GXD is timed to record images at four times as the capsule is imploding.

These targets are scaled down by 0.8× compared to the targets used during the National Ignition Campaign (NIC) in order to operate at reduced laser energy. The laser pulse, also shortened by 0.8×, is designed to be similar to the "low-foot" pulse used during NIC. The laser pulse has 0.9 MJ of energy and a peak power of 230 TW. The capsule for the DT layered experiment is 909 μm in radius with a 153 μm thick CH ablator and a DT ice layer that is 55 μm thick in the field of view. The ablator contains graded silicon dopant of up to 2.5% to block high-energy x-ray preheat. The symcap contains 10 μm of additional CH to account for the absent DT mass.

The target for the inner-surface perturbation experiment is shown in the right of Fig. 1. The ice layering process was precisely controlled so that the ice would be a uniform 55 μm thickness over ±90° and have minimal grooves within the field of view. The perturbation at the interface can be seen in the radiograph. This perturbation was imposed through a new technique using laser ablation[3]. After the hole for the Au cone was cut into the capsule, a UV laser was used to remove individual spots to create a sinusoidal mode 60 pattern. This technique also left

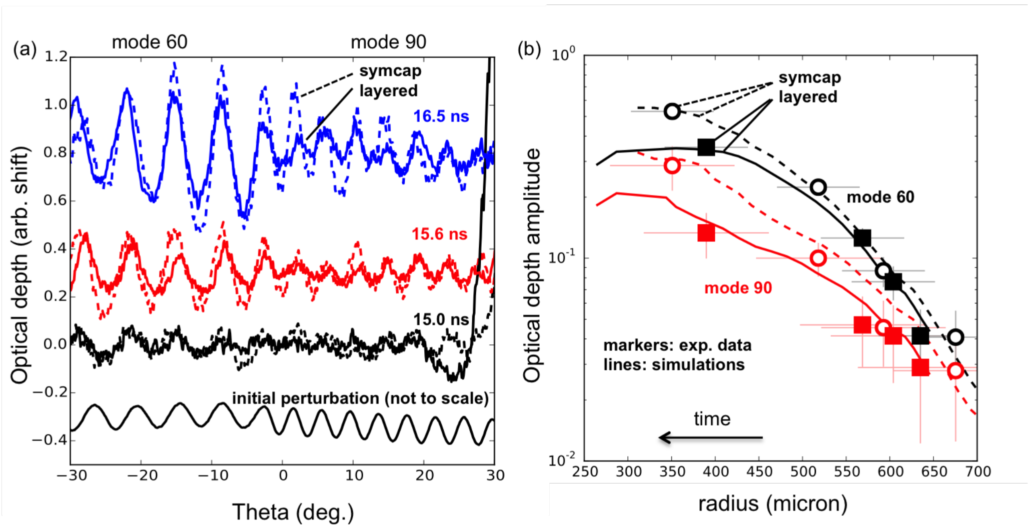

Figure 2. Outer-surface perturbation HGR experiments, comparing a layered capsule (solid) to a symcap (dashed). (a) Radiograph results converted to optical depth. The initial condition amplitude is shown at the bottom. (b) Single mode amplitudes vs. radius.

higher-mode features the size of the laser spot (mode ∼500). Because of these higher mode features and the small amplitude growth expected at the interface, only a single wavelength was included on this experiment to simplify the analysis.

The outer-surface perturbations for the comparison between the symcap and the layered capsule were made using a lathe technique, similar to past HGR experiments. Side-by-side perturbations of modes 60 and 90 and amplitude of 0.7 μm. These perturbations are shown at the bottom of Fig. 2(a).

3. Results

The results from outer-surface perturbation experiments are shown in shown in Fig. 2(a). The transmission signal was processed by removing the background signal, dividing by the backlighter profile, and converting to optical depth. Here the width of the data was converted to angle around the capsule by detecting the center of convergence between the various times. A similar amplitude is observed between the symcap (dashed) and layered capsule (solid) at the earliest time, but later in time the symcap appears to grow larger. This effect is reproduced in post-shot modeling and occurs when the ablation front growth feeds through to the interface. In the simulations, both capsules have the same ablation front perturbation amplitude and the same ρR ($\int \rho\, dr$) modulation, but the low opacity of the DT fuel to the x-ray backlighter compared to the CH results in less observed optical-depth ($\int \kappa\rho\, dr$) modulation.

The single mode amplitudes from these experiments are shown in Fig. 2(b) and compared with post-shot simulations using HYDRA[4]. Here the transfer function of the imaging system has been corrected for. Good agreement is found between the simulations and the data, with the simulation falling within the error bars of most data points. Both the experiments and the simulations show the optical depth modulation amplitude growing larger in the symcap than in the layered capsule. As mentioned previously, this is consistent with both the ablation front amplitude and the ρR amplitude being similar between the two capsules, but a lower optical depth modulation due to feed-through of growth to the interface and the low DT opacity.

Results from the experiment with a perturbation at the interface are shown in Fig. 3(a). The

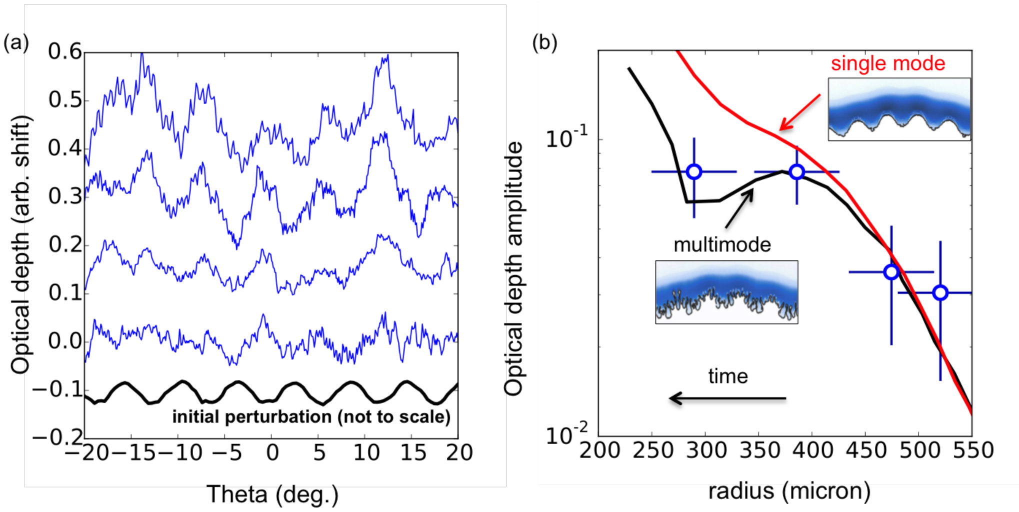

Figure 3. Inner-surface perturbation HGR experiment. (a) The initial condition is shown in black (not to scale) and the optical depth at four times is shown in blue. (b) Single mode amplitudes vs. radius. Simulations with and without the high-mode roughness are shown and images of the opacity ($\kappa\rho$) are inset.

2.2 μm amplitude mode 60 perturbation is shown at the bottom of this figure. The phase of the perturbation was expected to invert from the initial condition, but this cannot be constrained given the uncertainty in angle between the initial condition and the in-flight radiographs. In the data, moderate amplitude growth can be observed between the earliest and latest time. There are also variations in the modulations further from the center of the target (the spike at θ=10-15° appears larger than in the center). This is an effect also observed in simulations and appears to be due to the curvature of the capsule - rays going at an angle (rather than radially, as with θ=0°) have a longer path length (and optical depth).

The sinusoidal amplitude from the center three waves are shown in Fig. 3(b). Two post-shot calculations are also shown in this figure. When only mode 60 is included in the calculation and higher modes are filtered out, the simulation shows good agreement with the earlier time data but over-predicts the late-time growth. The high-mode structure, resulting from the laser-ablation process used to create the perturbation, is included in the “multimode” calculation. The growth in this case saturates later in time, with high modes coupling to lower modes. This case shows good agreement with all of the experimental data. This suggests that high-mode features may be influencing current measurements. Future experiments will seek to directly measure the growth of these small wavelengths.

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References
[1] Raman K S *et al.* 2014 *Phys. Plasmas* **21** 072710
[2] Smalyuk V A *et al.* 2014 *Phys. Rev. Lett.* **112** 185003
[3] Carlson L *et al.* 2015 *Fusion Sci. Tech.* **67**
[4] Marinak M M *et al.* 2001 *Phys. Plasmas* **8** 2275